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Developing Accurate Simulations of Correlated Data in Fission Events

LA14-FY14-027-PD2Jb

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1. INTRODUCTION

Our goal in this project is to implement new and unique fission physics capabilities in the MCNP6 transport code, to compute correlations in energy and angle of the prompt neutrons and gamma rays emitted in the fission process, and to validate this implementation through dedicated differential and integral experimental data.

In recent years, both LANL and LLNL/LBNL have been developing physics codes to simulate the de-excitation of the fragments typically produced in a fission event. Immediately after the nucleus undergoes binary fission, the two fragments quickly move away from each other and remove their excess excitation energy and spin by emitting prompt neutrons and gamma rays. Detailed characteristics of these evaporated particles are very important not only for a fundamental understanding of the fission process but also for applications relying on fission signatures.

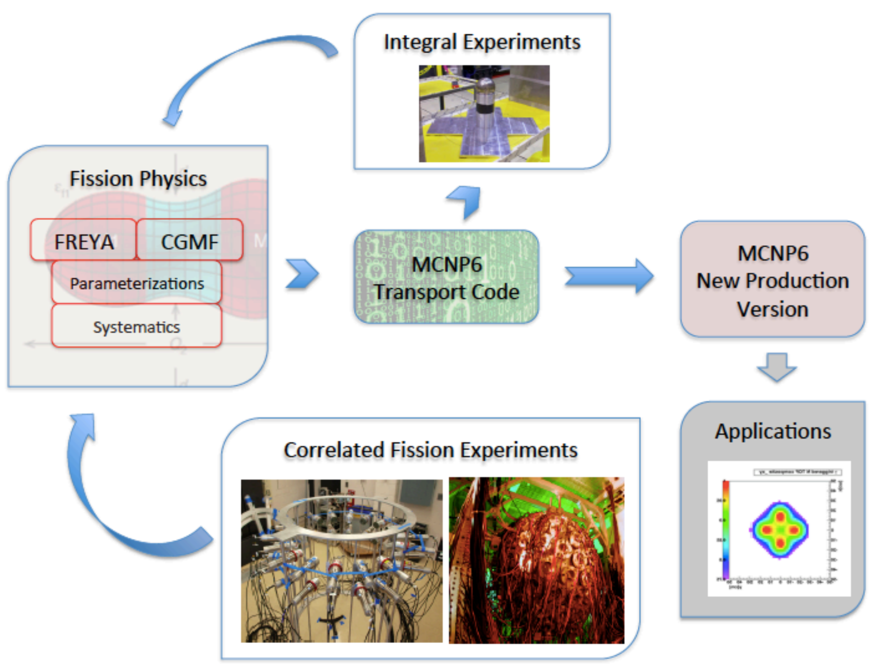

Figure 1 - New modeling of the physics of the fission process, validated through dedicated differential and integral experiments, is being implemented in a new version of the MCNP6 transport code for use in nuclear applications, including those dedicated to fission signatures.

2. TECHNICAL APPROACH

Several physics models and codes exist to describe the de-excitation of the fission fragments. Depending on the particular application or accuracy of the results required, different approximations could be used in a transport simulation. Our approach is to implement all those various models with increasing complexity into the well known, validated and documented MCNP6 code, and compare the numerical results against well-validated experimental data.

This year we have focused on the integration of the CGMF (LANL) and FREYA (LLNL/LBNL) physics codes into the MCNP6 transport code. After establishing the criteria for integrating those physics codes into MCNP6 at different stages of development (R&D, development branch, production), they have been incorporated at the most basic level (R&D) and will be moved progressively toward the Production level by the end of this project.

The physics models appearing in CGMF and FREYA are somewhat different but complementary. We will bring the best of both codes into a unique interface in MCNP6. The fission physics implemented in those codes will need to be validated through dedicated experiments.

The existing experimental database on correlations in fission is very scarce and does not allow us to answer specific and important questions that could impact the ongoing modeling efforts. We have proposed performing specific measurements on n-n, n-γ, γ-γ, and n-fragment correlations in energy and emission angle.

3. RESULTS, DISCUSSION AND CONCLUSIONS

The main results in this first year can be summarized as follows:

- We have written a reference document establishing the criteria for integration of our fission physics codes into MCNP6;
- Preliminary results using MCNP6 with correlated fission data were obtained;
- The modeling of prompt γ rays has been implemented and applied to selected fission reactions, and several papers have been published in refereed journals;
- Preliminary experimental results on n-n and γ-γ correlations in the spontaneous fission of Cf-252 have been obtained and are being analyzed.

This year, the University of Michigan has performed experiments on n-n and γ-γ correlations, which initial analysis already provides some interesting results against which our modeling codes will be compared. In particular, the preliminary results show that the angular distribution of the prompt neutrons is increased at 180°, as expected, while the distribution for the prompt gamma rays is nearly isotropic.

The experimental efforts using the DANCE calorimeter at Los Alamos will focus on correlations between the gamma rays and the fission fragments, for which existing data are limited and contradictory. Those efforts had to be postponed due to funding problems at the Lujan Center where the DANCE setup is located. We hope to perform this experiment in the first quarter of FY15 though.

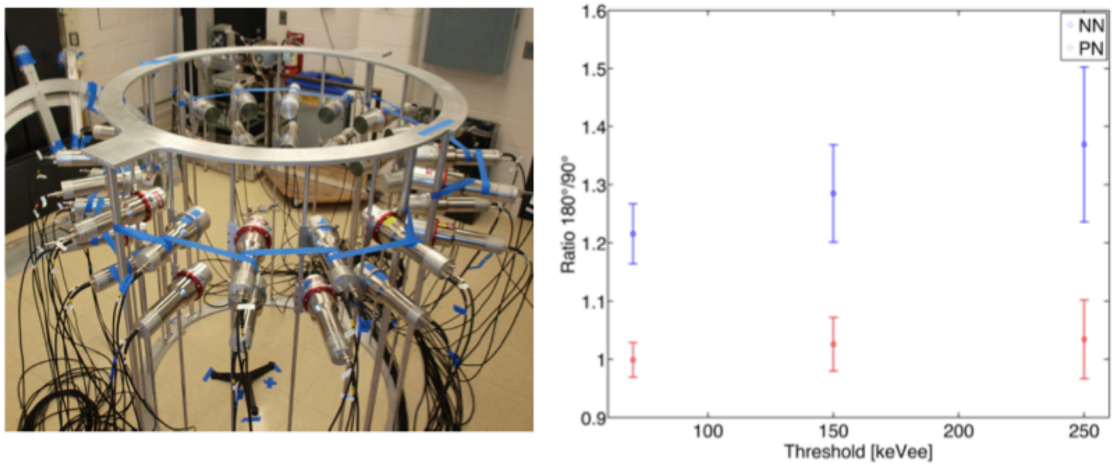

Figure 2 – (left) The experimental setup used at the University of Michigan to measure the neutron and gamma energy and angle correlations. (right) Neutron-neutron coincidences (blue) are larger at 180° and increase with increasing threshold, while no such trend could be found in the case of the prompt photons (red).

In the coming year, we plan to:

- Produce a new version of the MCNP6 code with correlated data in fission capabilities at the "Development" level;
- Extend the physics models in the fission codes to study reactions at higher excitation energies (other than thermal neutrons and spontaneous fission) and for more isotopes;
- Pursue the experimental efforts at Los Alamos and University of Michigan to put unique and stringent constraints on the fission models in our codes.

4. SELECTED PUBLICATIONS

- "Properties of prompt fission gamma rays," I.Stetcu, P.Talou, T.Kawano, and M.Jandel, Phys. Rev. C **90**, 024617 (2014).
- "Refined treatment of angular momentum in the event-by-event fission model FREYA," J.Randrup and R.Vogt, Phys. Rev. C **89**, 044601 (2014).
- "Fission Reaction Event Yield Algorithm FREYA for Event-by-Event Simulation of Fission," J.M.Verbeke, J.Randrup, and R.Vogt, *submitted for publication to Computer Physics Communication.*
- FREYA User Manual, LLNL-TM-654899.
- CGMF User Manual, LA-UR-14-24031.
- More than 7 Invited and Contributed Talks at Conferences